LTDR AVHRR Products (Version 5) User's Guide

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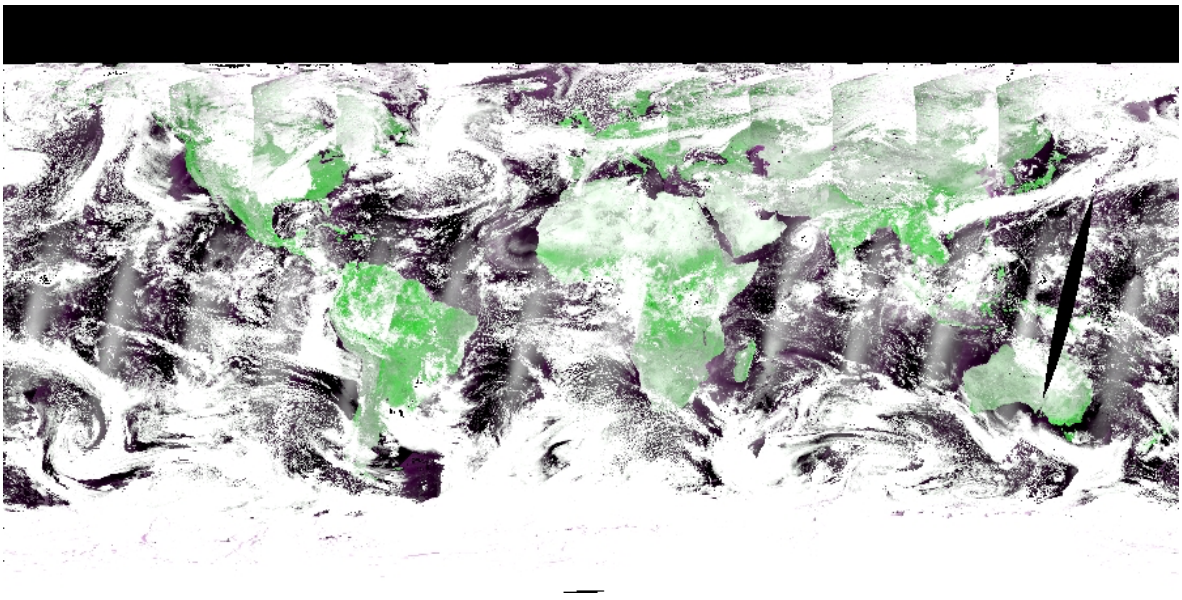

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1. Introduction

The Advanced Very High Resolution Radiometer (AVHRR) instrument has been one of several instruments aboard the TIROS/NOAA series of Sun-synchronous weather satellites (TIROS-N up to and including NOAA-19), and on the current MetOP series of weather satellites (MetOP-A through MetOP-C). The current version of AVHRR, AVHRR/3, reads Earth observations in six spectral channels (see Table 1).

Table 1. AVHRR/3 channels.

Channel	Spectral Bandpass (μm)
1 (visible)	0.580 - 0.68
2 (near infrared)	0.725 - 1.00
3A (near infrared)	1.580 - 1.64
3B (infrared)	3.550 - 3.93
4 (infrared)	10.300 - 11.3
5 (infrared)	11.500 - 12.5

Data from channels l, 2, and 3A are used to monitor reflected energy in the visible and near-IR portions of the electromagnetic spectrum. These data are typically used to observe vegetation, clouds, lakes, shorelines, snow, aerosols, and ice. Data from channels 3B, 4 and 5 are used to determine the radiative energy from the land, water, and sea surface, as well as of the clouds above them. Only five channels can be transmitted simultaneously, thus, channels 3A and 3B are alternated for day/night operation respectively.

AVHRR/3 is an across-track scanning system with a scan range of ±55.37° with respect to the nadir direction. There are 2048 Earth views per scan and per channel for a swath width of about 1447 km. An on-board processor samples the AVHRR/3 data to produce reduced resolution Global Area Coverage (GAC) data at a nominal resolution of 4 km at nadir. GAC data is the only type of AVHRR data used by the LTDR project.

The LTDR project's mission has been to establish a Land Long Term Data Record, including AVHRR data, beginning with NOAA-07 in 1981 and continuing to the present. Present-day AVHRR data can then be compared to Earth observation data from the Moderate Resolution Imagine Spectroradiometer (MODIS) instrument (2000 to the present) and the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument (2018 to the present), with the comparisons then serving as a source of vicarious calibration for current AVHRR data and data dating back to 1981.

This document describes the products from the latest version of LTDR's AVHRR processing, version 5.

2. Overview of the LTDR Version 5 Processing

The LTDR products are generated from AVHRR L1b GAC data. The processing of L1b files consists of various preprocessing steps which are based in (1) the AVHRR Pathfinder II project (correction for water vapor, Rayleigh scattering and ozone; see Ouaidrari et al., 2003); (2) the atmospheric correction scheme used in the Moderate Resolution Imaging Spectroradiometer (MODIS); and (3) in the Bidirectional Reflectance Distribution Function (BRDF) normalization approach proposed by Vermote, Justice, and Breon (2009). The primary processing program is called "GAPS": the **G**lobal Inventory Modeling and Mapping Studies (GIMMS) **A**dvanced **P**rocessing **S**ystem. Figure 1 shows the main processing steps in GAPS used to generate a daily LTDR file from corresponding AVHRR L1b GAC data. These steps are detailed further down in the document.

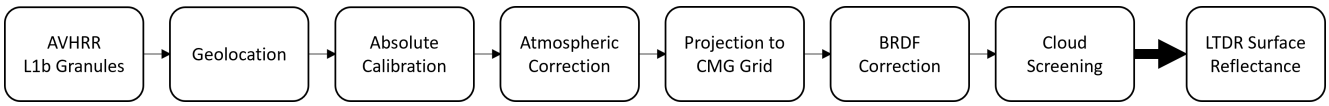

Figure 1. Processing steps for the generation of an AVHRR LTDR file

2.1 Geolocation

Data is geolocated using one-line ephemeris data from either SeaSpace,from the Office of Naval Research (NOAA satellites), or by using geolocation data included in the GAC data itself (MetOP satellites), which, being subsampled, is extended to the whole scanline by interpolation.

2.2 Absolute calibration

Calibration of AVHRR data is done through the "Ocean and Clouds" method (Vermote & Kaufman, 1995). This method uses observation over high-altitude, bright clouds to inter-calibrate the Red and NIR bands. Off-nadir ocean observations are then used for the absolute calibration of the Red band, which signal (after accounting for aerosols) can be accurately estimated by radiative transfer simulations. Results from the "Ocean and Clouds" method were found to be consistent within 1% to calibration coefficients derived with an approach based on observations over desert sites (Vermote & Saleous, 2006).

2.3 Atmospheric Correction

Atmospheric constituents can affect the signal measured by AVHRR through the scattering and absorption processes. The atmospheric correction process attempts to estimate and remove these effects from the signal measured by a remote sensor. This process depends primarily on (1) the model selected to simulate the influence of the atmospheric constituents on the at-sensor signal, and (2) on the method or ancillary information used to describe said constituents.

The LTDR atmospheric correction for the Red and NIR bands is based on Equation 1, which describes the reflectance from a Lambertian target measured by the AVHRR sensor at the top of the atmosphere:

$$\rho_{TOA} = Tg_{O2}Tg_{O3}\left(\rho_R + \frac{T_R Tg_{H2O}\rho_S}{1 - S\rho_S}\right) \qquad (1)$$

where ρ_{TOA} is the reflectance at the top of the atmosphere; $\rho_S$is the reflectance at surface level; Tg_{O2}, Tg_{O3}, and Tg_{H2O} are the transmittance for oxygen, ozone, and water vapor, respectively; and ρ_R, T_R, and S are the Rayleigh atmospheric reflectance, transmittance, and spherical albedo, respectively. For the LTDR, Rayleigh contributions are modeled using analytical formulas from Vermote & Tanre (1992), and the atmospheric gases influence on the AVHRR signal is simulated with the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) radiative transfer code (Vermote et al., 1997). In the case of band 3B, where the measured radiance is a combination of both reflected and emitted components, the surface reflectance is estimated using the method proposed by Roger & Vermote (1998).

Information of atmospheric variables and constituents is obtained from satellite data, gridded observations, and reanalysis sources. The selection of which data source to use depends on the AVHRR temporal period and on ancillary data availability. *Table 2* shows a summary of the ancillary data used for atmospheric characterization.

Table 2. Ancillary data used for LTDR atmospheric correction over land.

Sources[1]	Variables[2]	Period	Spatial Resolution[3]	Temporal Resolution
MODIS	WV	2000 – present	0.05° x 0.05°	daily
TOMS	O3	1984 – 2005	1.00° x 1.25°	daily
NCEP/GDAS	O3/WV/P	2000 – present	1.00° x 1.00°	6 hours
NCEP R1	O3/WV/P	1984 – present	2.50° x 2.50°	6 hours
[1]Data selection is prioritized as: MODIS/TOMS → NCEP/GDAS → NCEP R1 [2]O3: Ozone; WV: Water Vapor; P: Surface Pressure [3]Spatial resolution is shown in latitude x longitude				

2.4 Projection to CMG grid

The LTDR products are distributed in a fixed 0.05° Climate Modeling Grid (CMG) format (Plate Carrée, 20 pixels per degree), with latitudes ordered from 90 to -90 degrees and longitudes from -180 to 180 degrees. All GAPS output data are composited into the CMG in two phases; by averaging data within one orbit, and by selecting data with the minimum solar zenith angle where orbits overlap, and more than one valid observation is available.

2.5 Normalization of directional effects (BRDF normalization)

The LTDR provides surface reflectance that has been normalized to a standard observation geometry (sun zenith angle of 45°; view zenith angle of 0°; and relative azimuth angle of 0°). This minimizes signal variations of individual observations that are caused by changes in sun-sensor geometry. In the LTDR, the Bidirectional Reflectance Distribution Function (BRDF) effects are normalized with the VJB method (Vermote, Justice, and Breon, 2009) using BRDF parameters derived from MODIS data. The use of these parameters to correct AVHRR data was explored in Villaescusa-Nadal et al. (2019). The study shows that the time-series noise in bands 1 and 2 caused by varying illumination and observation conditions can be reduced using MODIS-derived BRDF parameters on AVHRR data. This noise reduction is comparable (and in occasions superior), to using AVHRR-derived BRDF parameters.

2.6 Cloud Screening

Cloud screening is performed by comparing the BRDF-corrected AVHRR surface reflectance against thresholds derived from monthly 10-year climatological values of MODIS Aqua Red and NIR BRDF-corrected reflectances. This method was analyzed in Franch et al. (2017) and Villaescusa-Nadal et al. (2021) and was found to detect clouds with omission and commission errors below 5%.

The LTDR products have Earth Science Data Types (ESDTs), metadata and file-naming characteristics like those found in MODIS processing. LTDR data is distributed in the HDF4 file format, although some types of files are available in NetCDF, and follow NetCDF's Climate and Forecast metadata conventions (see section 3.8, "Additional Products"). All NetCDF products have an "_NC" string added to the end of their ESDT. Leaf Area Index (LAI) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) are calculated according to the method described in Claverie et al. (2016).

Table 3. LTDR products

ESDT	Description
xx_AVH01C1	Product containing BRDF-corrected surface reflectance data, top-of-atmosphere reflectance data, brightness temperature data, solar and view angles, derived aerosols over oceans, and the parameters used in the BRDF correction.
xx_AVH02C1	Product derived from xx_AVH01C1, containing top-of-atmosphere reflectance data, brightness temperature data, and angles.
xx_AVH09C1	Product derived from xx_AVH01C1, containing BRDF-corrected surface reflectance data, brightness temperature data, and angles.
xx_AVH13C1	Product derived from xx_AVH01C1, containing NDVI.
xx_AVH15C1	Product derived from xx_AVH01C1 or xx_ AVH09C1, containing LAI and FAPAR

where 'xx' corresponds to the satellite of origin of the AVHRR data: "N07" for NOAA-07, "N09" for NOAA-09, up to "N19" for NOAA-19, and "M1" for MetOP-B (see section 3.9, "Satellites from which AVHRR data was processed"). All products also contain quality control data.

These products are available at the Level 1 and Atmosphere Archive and Distribution System (LAADS) Distributed Active Archive Center (DAAC), archive set 465, although 1) AVH01C1 data at that archive set is only available from MetOP-B, and 2) the AVH15C1 product is available from each satellite and is processed in both NetCDF and HDF4 output versions, but only the NetCDF version is at archive set 465. The rest of this document will refer to the ESDTs without their satellite prefix, and illustrative material will be derived from examples of MetOP-B products.

3. Detailed product descriptions

3.1. AVH01C1 files

GIMMS Advanced Processing System (GAPS) BRDF-corrected Surface Reflectance from AVHRR inputs
Product description: The GAPS algorithm provides BRDF-corrected surface reflectance for bands 1 and 2, surface reflectance for band 3, top-of-atmosphere reflectance for bands 1 and 2, and aerosol retrieval. It also provides data Quality flags, angles (solar zenith, view zenith, and relative azimuth), ancillary data (water vapor, ozone), thermal data (thermal bands 3, 4 and 5), and additional data (parameters used in the BRDF correction, latitude, longitude, scan time, and the number of AVHRR pixels projecting to each CMG pixel) , in the HDF4 format.

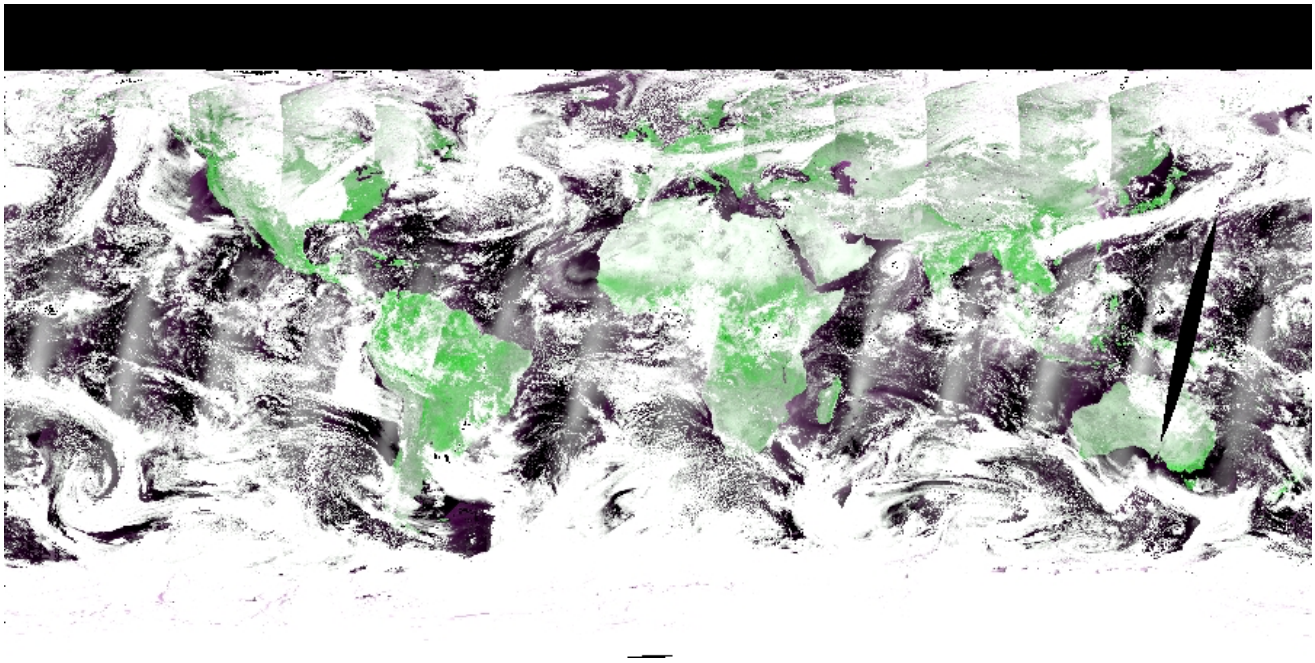

Figure 2. An AVH01C1 RGB-image composed of surface reflectance measured by AVHRR bands RHO1 (blue and red) and RHO2 (green), October 28, 2019. Product granule ID: M1_AVH01C1.A2019301.005.2021118115711.hdf.

Table 4. Science Data Sets for AVH01C1 files.

SDS Name	SDS Contents	Units	Data Type	Valid Range	Scale Factor
RHO1	Surface Reflectance Band 1	N/A	16-bit signed integer	-1000 – 10000	0.0001
RHO2	Surface Reflectance Band 2	N/A	16-bit signed integer	-1000 – 10000	0.0001
T3	Brightness Temperature Band 3	Kelvin	16-bit signed integer	0 – 4000	0.1
T4	Brightness Temperature Band 4	Kelvin	16-bit signed integer	0 – 4000	0.1

T5	Brightness Temperature Band 5	Kelvin	16-bit signed integer	0 – 4000	0.1
RHO3	Surface Reflectance Band 3	N/A	16-bit signed integer	-1000 – 10000	0.0001
TOA1	Top-Of-Atmosphere Reflectance Band 1	N/A	16-bit signed integer	-1000 – 10000	0.0001
TOA2	Top-Of-Atmosphere Reflectance Band 2	N/A	16-bit signed integer	-1000 – 10000	0.0001
WV	Water Vapor	g/cm^2	16-bit signed integer	0 – 8000	0.001
O3	Ozone	Dobson	16-bit signed integer	0 – 800	0.001
TIME	Time of day	HHFH (hour, fraction of hour)	16-bit signed integer	0 – 2399	0.01
LAT	Latitude	Degrees	16-bit signed integer	-180 – 180	0.01
LON	Longitude	Degrees	16-bit signed integer	-90 – 90	0.01
TS	Solar Zenith angle	Degrees	16-bit signed integer	0 – 90	0.01
TV	View Zenith angle	Degrees	16-bit signed integer	0 – 90	0.01
PHI	Relative Azimuth angle	Degrees	16-bit signed integer	-180 – 180	0.01
AOT1	Aerosol optical thickness, band 1	N/A	16-bit signed integer	0 – 2000	0.001
AOT2	Aerosol optical thickness, band 2	N/A	16-bit signed integer	0 – 2000	0.001
BRDF_R1	Surface scattering BRDF parameter	N/A	16-bit signed integer	-100 – 300	0.001
BRDF_V1	Volume scattering BRDF parameter	N/A	16-bit signed integer	0 – 300	0.001
BRDF_QA	BRDF process Quality Flags *(see* **Table 10***)*	Bit field	16-bit signed integer	0 – 255	N/A
QC	Quality Flags *(see* **Table 11***)*	Bit field	16-bit signed integer	0 – 20000	N/A
ORBDATE	Julian date (D) plus orbit number (N) in a bit field (…DDDDDNNNNN)	Bit field	16-bit signed integer	32 – 12000	N/A
n	Total number of GAC pixels mapping to this pixel	(none)	8-bit unsigned integer	0 – 20	1
N_MAPPING	Number of GAC pixels mapping to this pixel in categories	Bit field	32-bit unsigned integer	0 – 10000000	N/A

	(cloudy, clear, etc.) *(see* **Table 12***)*				

Description of Metadata: Example of M1_AVH01C1.A2019301.005.2021118115711.hdf

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LOCALVERSIONID = SCF V4.0
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NORTHBOUNDINGCOORDINATE = 90.0
PGEVERSION = 1.0.12
PROCESSINGCENTER = MODAPS
PROCESSINGENVIRONMENT = Linux moddev-c7 3.10.0-1160.21.1.el7.x86_64 #1 SMP Tue Mar 16 18:28:22 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
PRODUCTIONDATETIME = 2021-04-29T10:03:20.000Z
PRODUCTIONHISTORY = GAPS:v54
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RANGEENDINGTIME = 23:59:59.000000
REPROCESSINGACTUAL = Near Real Time
REPROCESSINGPLANNED = further update is anticipated
SHORTNAME = M1_AVH01C1
SOUTHBOUNDINGCOORDINATE = -90.0
SPSOPARAMETERS = None
VERSIONID = 54
WESTBOUNDINGCOORDINATE = -180.0

3.2. AVH02C1 files

METOP-B AVHRR Top-of-Atmosphere Reflectance Daily L3 Global 0.05 Deg CMG

Product description: Top-of-atmosphere reflectance for bands 1 and 2, data Quality flags, angles (solar zenith, view zenith, and relative azimuth), thermal data (thermal bands 3, 4 and 5), and additional data (scan time), is read from the GAPS product (AVH01C1) and written to the AVH02C1 product, in the HDF4 format.

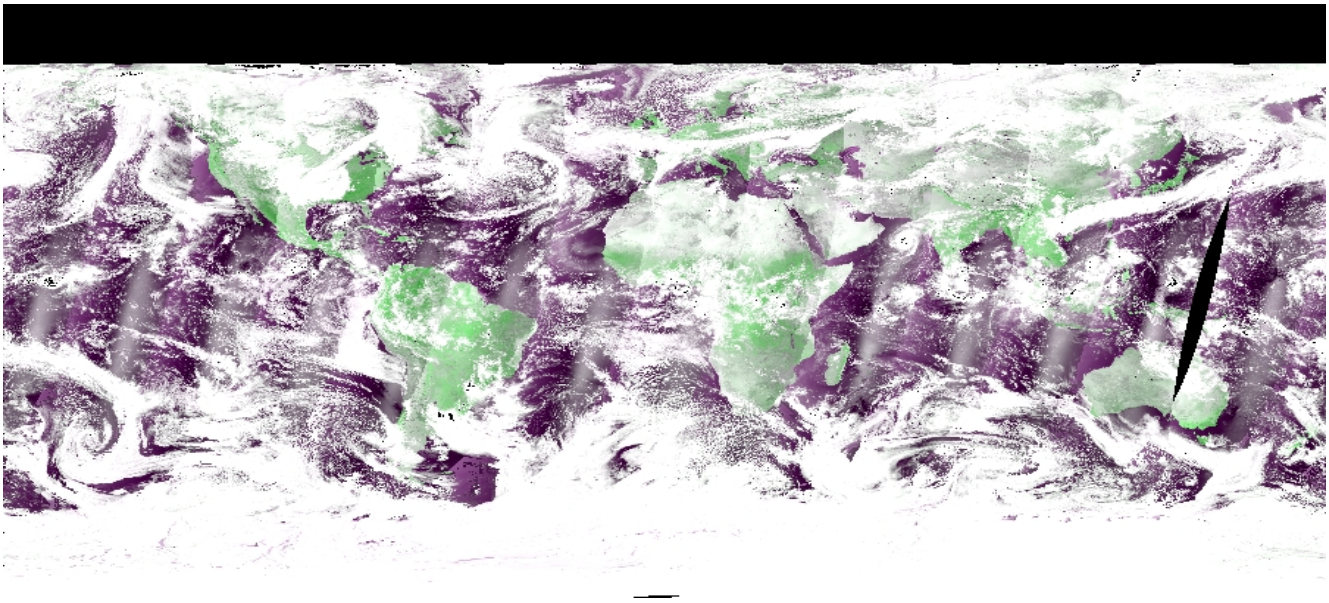

Figure 3. An AVH02C1 RGB-image composed of top-of-atmosphere reflectance measured by AVHRR bands RHO1 (blue and red) and RHO2 (green), October 28, 2019. Product granule ID: M1_AVH02C1.A2019301.005.2021118115711.hdf.

Table 5. Science Data Sets for AVH02C1 files.

SDS Name	SDS Contents	Units	Data Type	Fill Value	Valid Range	Scale Factor
TOA_REFL_CH1	Top-Of-Atmosphere Reflectance Band 1	N/A	16-bit signed integer	-9999	-1000 – 10000	0.0001
TOA_REFL_CH2	Top-Of-Atmosphere Reflectance Band 2	N/A	16-bit signed integer	-9999	-1000 – 10000	0.0001
BT_CH3	Brightness Tempera-ture Band 3	Kelvin	16-bit signed integer	-9999	0 – 4000	0.1
BT_CH4	Brightness Tempera-ture Band 4	Kelvin	16-bit signed integer	-9999	0 – 4000	0.1
BT_CH5	Brightness Tempera-ture Band 5	Kelvin	16-bit signed integer	-9999	0 – 4000	0.1
SZEN	Solar Zenith angle	Degrees	16-bit signed integer	-9999	-9000 – 9000	0.01
VZEN	View Zenith angle	Degrees	16-bit signed integer	-9999	-7000 – 7000	0.01

RELAZ	Relative Azimuth angle	Degrees	16-bit signed integer	-9999	-18000 – 18000	0.01
TIME	Time of day	HHFH (hour, fraction of hour)	16-bit signed integer	-9999	0 – 2399	0.01
QA	Quality Flags *(see* **Table 11***)*	Bit field	16-bit signed integer	832[a]	N/A	N/A

[a] – a fill value of 832 represents invalid data in channels 1 and 2 and nighttime solar zenith values.

Description of Metadata: Example of M1_AVH02C1.A2019301.005.2021118115711.hdf

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10.5067/AVHRR/M1_AVH02C1.005
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ADDITIONALATTRIBUTESCONTAINER.2: PARAMETERVALUE.2 = https://www.doi.org
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDINSTRUMENTSHORTNAME.1 = AVHRR
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDPLATFORMSHORTNAME.1 = METOP_B
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDSENSORSHORTNAME.1 = AVHRR
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DESCRREVISION = 1.0
EASTBOUNDINGCOORDINATE = 180.0
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LOCALGRANULEID = M1_AVH02C1.A2019301.005.2021118115711.hdf
LOCALITYVALUE = Global
LOCALVERSIONID = SCF V5.0
LONGNAME = METOP-B AVHRR Top-of-Atmosphere Reflectance Daily L3 Global 0.05 Deg CMG
NORTHBOUNDINGCOORDINATE = 90.0
PGEVERSION = 1.0.12
PROCESSINGCENTER = MODAPS
PROCESSINGENVIRONMENT = Linux moddev-c7 3.10.0-1160.21.1.el7.x86_64 #1 SMP Tue Mar 16 18:28:22 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
PRODUCTIONDATETIME = 2021-04-28T11:57:11.000Z
PRODUCTIONHISTORY = PGE199:1.0.12;LTDR_GAPS:3.5.54
RANGEBEGINNINGDATE = 2019-10-28
RANGEBEGINNINGTIME = 00:00:00.000000
RANGEENDINGDATE = 2019-10-28
RANGEENDINGTIME = 23:59:59.000000
REPROCESSINGACTUAL = Near Real Time
REPROCESSINGPLANNED = further update is anticipated
SHORTNAME = M1_AVH02C1
SOUTHBOUNDINGCOORDINATE = -90.0
SPSOPARAMETERS = None
VERSIONID = 5
WESTBOUNDINGCOORDINATE = -180.0

3.3. AVH09C1 files

METOP-B AVHRR Atmospherically Corrected Surface Reflectance Daily L3 Global 0.05 Deg CMG.

Product description: BRDF-corrected surface reflectance for bands 1, 2 and 3, data Quality flags, angles (solar zenith, view zenith, and relative azimuth), and thermal data (thermal bands 3, 4 and 5) is read from the GAPS product (AVH01C1) and written to the AVH09C1 product, in the HDF4 format

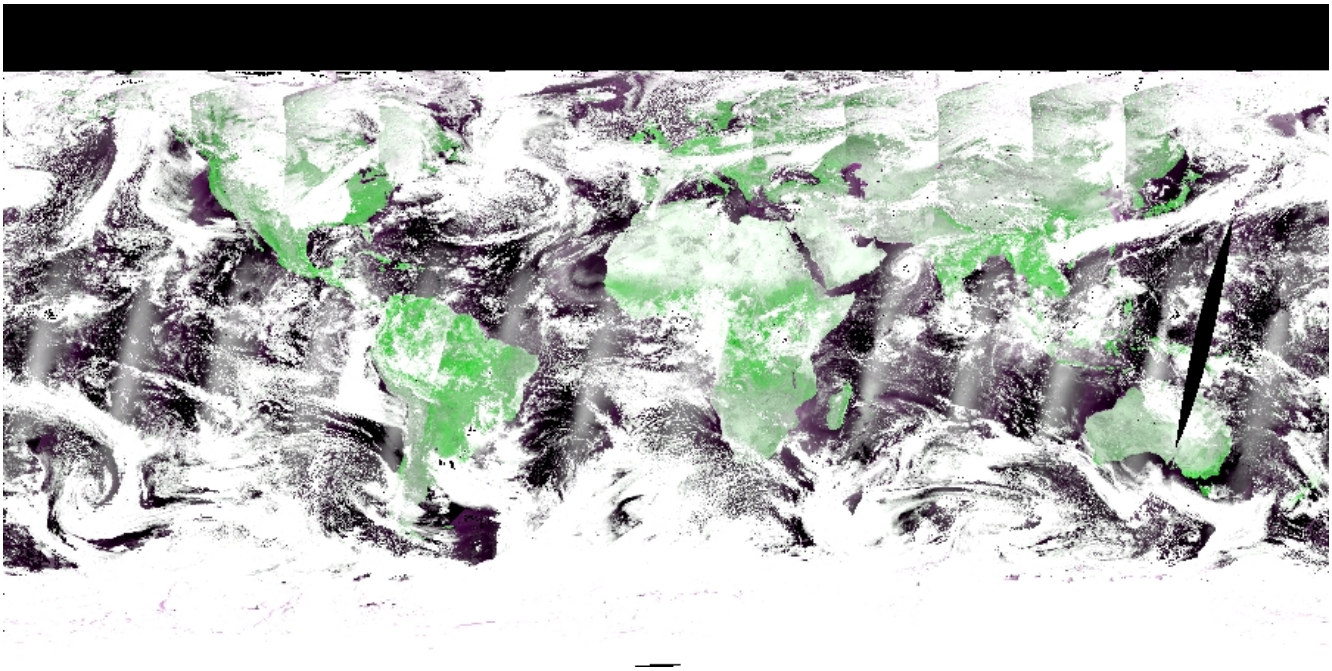

Figure 4. An AVH09C1 RGB-image composed of surface reflectance measured by AVHRR bands RHO1 (blue and red) and RHO2 (green), October 28, 2019. Product granule ID: M1_AVH09C1.A2019301.005.2021118115711.hdf.

Table 6. Science Data Sets for AVH09C1 files.

SDS Name	SDS Contents	Units	Data Type	Fill Value	Valid Range	Scale Factor
SREFL_CH1	Surface Reflectance Band 1	N/A	16-bit signed integer	-9999	-1000 – 10000	0.0001
SREFL_CH2	Surface Reflectance Band 2	N/A	16-bit signed integer	-9999	-1000 – 10000	0.0001
BT_CH3	Brightness Tempera-ture Band 3	Kelvin	16-bit signed integer	-9999	0 – 4000	0.1
BT_CH4	Brightness Tempera-ture Band 4	Kelvin	16-bit signed integer	-9999	0 – 4000	0.1
BT_CH5	Brightness Tempera-ture Band 5	Kelvin	16-bit signed integer	-9999	0 – 4000	0.1
SREFL_CH3	Surface Reflectance Band 3	N/A	16-bit signed integer	-9999	-1000 – 10000	0.0001

SZEN	Solar Zenith angle	Degrees	16-bit signed integer	-9999	-9000 – 9000	0.01
VZEN	View Zenith angle	Degrees	16-bit signed integer	-9999	-7000 – 7000	0.01
RELAZ	Relative Azimuth angle	Degrees	16-bit signed integer	-9999	-18000 – 18000	0.01
QA	Quality Flags *(see* **Table 11***)*	Bit field	16-bit signed integer	832[a]	N/A	N/A

[a] – a fill value of 832 represents invalid data in channels 1 and 2 and nighttime solar zenith values.

Description of Metadata: Example of M1_AVH09C1.A2019301.005.2021118115711.hdf

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10.5067/AVHRR/M1_AVH09C1.005
ADDITIONALATTRIBUTESCONTAINER.2: ADDITIONALATTRIBUTENAME.2 = identifier_product_doi_authority
ADDITIONALATTRIBUTESCONTAINER.2: PARAMETERVALUE.2 = https://www.doi.org
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDINSTRUMENTSHORTNAME.1 = AVHRR
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDPLATFORMSHORTNAME.1 = METOP_B
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDSENSORSHORTNAME.1 = AVHRR
DAYNIGHTFLAG = DAY
DESCRREVISION = 1.0
EASTBOUNDINGCOORDINATE = 180.0
INPUTPOINTER = M1_AVH01C1.A2019301.005.2021118115711.hdf
LOCALGRANULEID = M1_AVH09C1.A2019301.005.2021118115711.hdf
LOCALITYVALUE = Global
LOCALVERSIONID = SCF V5.0
LONGNAME = METOP-B AVHRR Atmospherically Corrected Surface Reflectance Daily L3 Global 0.05 Deg CMG
NORTHBOUNDINGCOORDINATE = 90.0
PGEVERSION = 1.0.12
PROCESSINGCENTER = MODAPS
PROCESSINGENVIRONMENT = Linux moddev-c7 3.10.0-1160.21.1.el7.x86_64 #1 SMP Tue Mar 16 18:28:22 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
PRODUCTIONDATETIME = 2021-04-28T11:57:11.000Z
PRODUCTIONHISTORY = PGE199:1.0.12;LTDR_GAPS:3.5.54
RANGEBEGINNINGDATE = 2019-10-28
RANGEBEGINNINGTIME = 00:00:00.000000
RANGEENDINGDATE = 2019-10-28
RANGEENDINGTIME = 23:59:59.000000
REPROCESSINGACTUAL = Near Real Time
REPROCESSINGPLANNED = further update is anticipated
SHORTNAME = M1_AVH09C1
SOUTHBOUNDINGCOORDINATE = -90.0
SPSOPARAMETERS = None
VERSIONID = 5
WESTBOUNDINGCOORDINATE = -180.0

3.4. AVH13C1 files

METOP-B AVHRR Atmospherically Corrected Normalized Difference Vegetation Index Daily L3 Global 0.05 Deg CMG.

Product description: Normalized Difference Vegetation Index (NDVI) and data Quality is calculated from the GAPS product's BRDF-corrected surface reflectance (AVH01C1) and written to the AVH13C1 product, in the HDF4 format

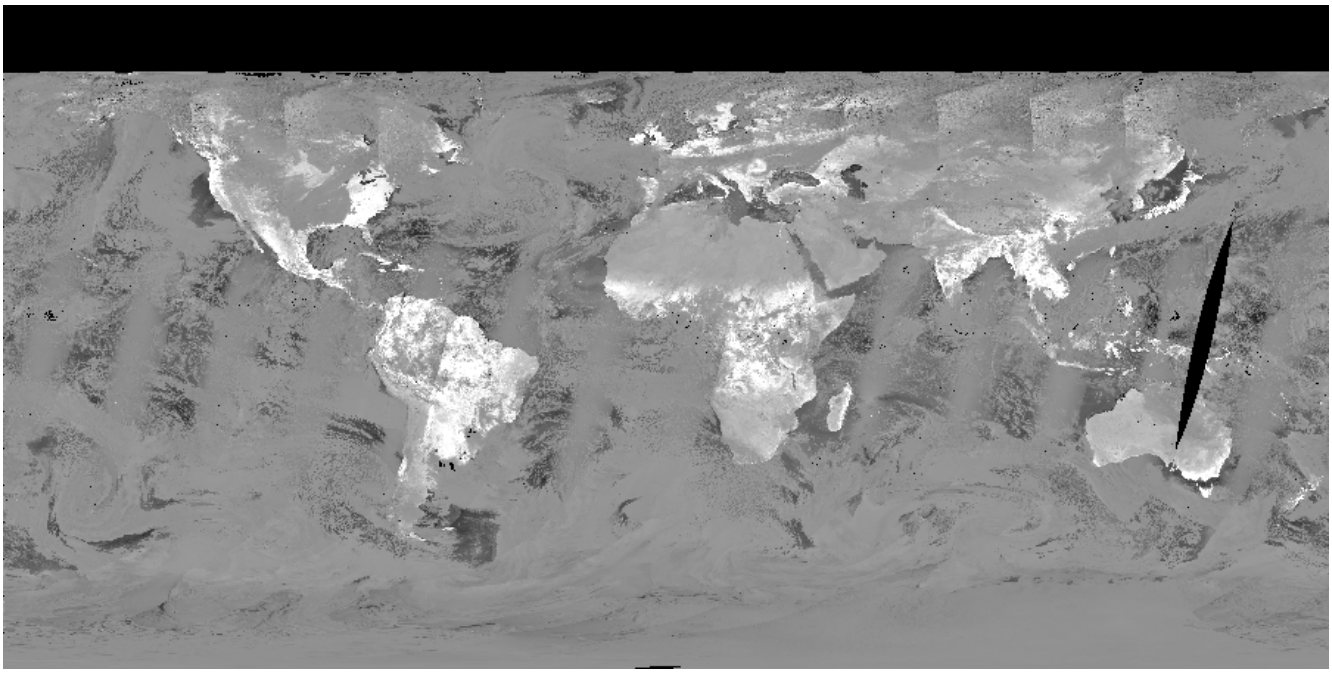

Figure 5. An image composed of NDVI values, October 28, 2019. Product granule ID: M1_AVH13C1.A2019301.005.2021118115711.hdf.

Table 7. Science data sets for AVH13C1 files

SDS Name	SDS Contents	Units	Data Type	Fill Value	Valid Range	Scale Factor
NDVI	Normalized Difference Vegetation Index	N/A	16-bit signed integer	-9999	-1000 – 10000	0.0001
QA	Quality Flags *(see* **Table 11***)*	Bit field	16-bit signed integer	320[a]	N/A	N/A

[a] – a fill value of 320 represents invalid data in channel 1 and nighttime solar zenith values.

Description of Metadata:
Example of M1_AVH13C1.A2019301.005.2021118115711.hdf

ADDITIONALATTRIBUTESCONTAINER.1: ADDITIONALATTRIBUTENAME.1 = identifier_product_doi

ADDITIONALATTRIBUTESCONTAINER.1: PARAMETERVALUE.1 =
10.5067/AVHRR/M1_AVH13C1.005
ADDITIONALATTRIBUTESCONTAINER.2: ADDITIONALATTRIBUTENAME.2 = identifier_product_doi_authority
ADDITIONALATTRIBUTESCONTAINER.2: PARAMETERVALUE.2 = https://www.doi.org
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDINSTRUMENTSHORTNAME.1 = AVHRR
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDPLATFORMSHORTNAME.1 = METOP_B
ASSOCIATEDPLATFORMINSTRUMENTSENSORCONTAINER.1: ASSOCIATEDSENSORSHORTNAME.1 = AVHRR
DAYNIGHTFLAG = DAY
DESCRREVISION = 1.0
EASTBOUNDINGCOORDINATE = 180.0
INPUTPOINTER = M1_AVH01C1.A2019301.005.2021118115711.hdf
LOCALGRANULEID = M1_AVH13C1.A2019301.005.2021118115711.hdf
LOCALITYVALUE = Global
LOCALVERSIONID = SCF V5.0
LONGNAME = METOP-B AVHRR Atmospherically Corrected Normalized Difference Vegetation Index Daily L3 Global 0.05 Deg CMG
NORTHBOUNDINGCOORDINATE = 90.0
PGEVERSION = 1.0.12
PROCESSINGCENTER = MODAPS
PROCESSINGENVIRONMENT = Linux moddev-c7 3.10.0-1160.21.1.el7.x86_64 #1 SMP Tue Mar 16 18:28:22 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
PRODUCTIONDATETIME = 2021-04-28T11:57:11.000Z
PRODUCTIONHISTORY = PGE199:1.0.12;LTDR_GAPS:3.5.54
RANGEBEGINNINGDATE = 2019-10-28
RANGEBEGINNINGTIME = 00:00:00.000000
RANGEENDINGDATE = 2019-10-28
RANGEENDINGTIME = 23:59:59.000000
REPROCESSINGACTUAL = Near Real Time
REPROCESSINGPLANNED = further update is anticipated
SHORTNAME = M1_AVH13C1
SOUTHBOUNDINGCOORDINATE = -90.0
SPSOPARAMETERS = None
VERSIONID = 5
WESTBOUNDINGCOORDINATE = -180.0

3.5. AVH15C1 files

METOP-B AVHRR Atmospherically Corrected Leaf Area Index and Fraction of Absorbed Photosynthetically Active Radiation Daily L3 Global 0.05 Deg CMG.

Product description: Leaf Area Index (LAI) and Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and data Quality is calculated from the GAPS product's BRDF-corrected surface reflectance (AVH01C1) and written to the AVH15C1 product, in the NetCDF format.

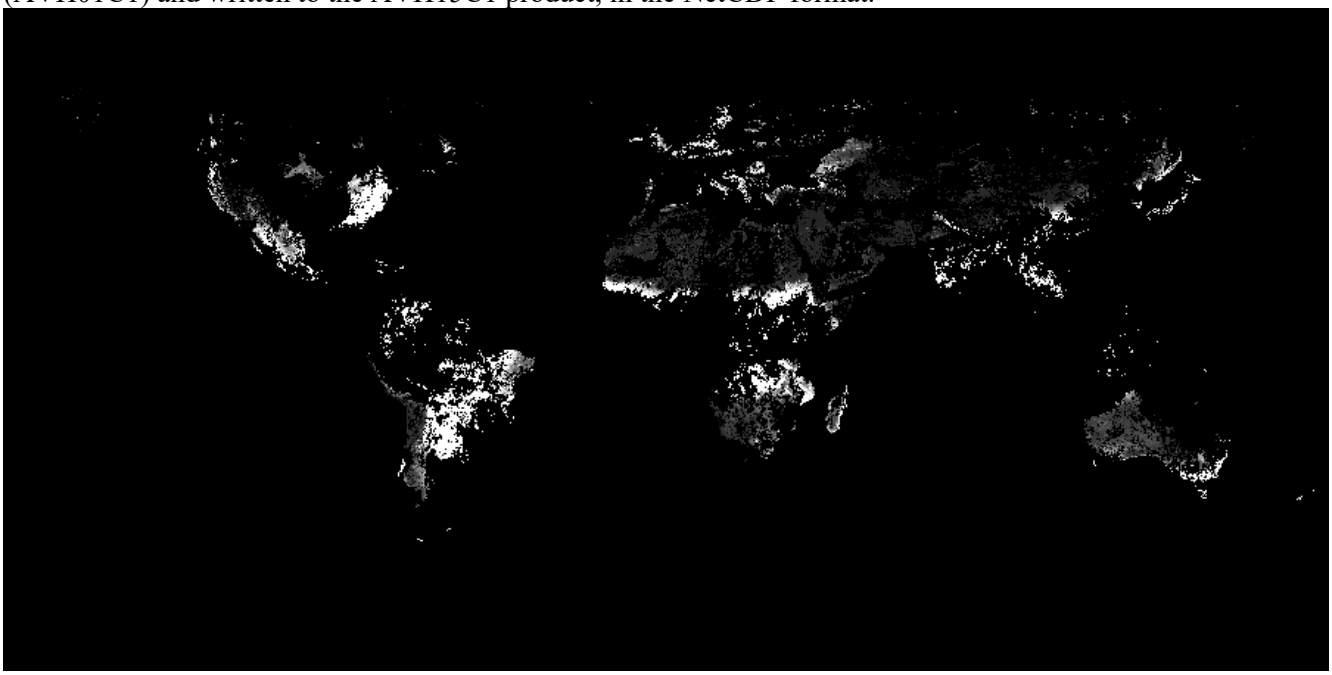

Figure 6. An image composed of LAI values, October 28, 2019. Product granule ID: AVHRR-Land_v005-preliminary_AVH15C1_METOP-B_20191028_c20210428160140.nc.

Table 8. Science Data Sets for AVH15C1 files.

SDS Name	SDS Contents	Units	Data Type	Fill Value	Valid Range	Scale Factor
FAPAR	FAPAR values	N/A	16-bit signed integer	-100	0 – 1000	0.001
LAI	LAI values	N/A	16-bit signed integer	-100	0 – 7000	0.001
QA	Quality Flags *(see* **Table 9***)*	Bit field	16-bit unsigned integer	282[a]	1 – 280	N/A

[a] – 282 is the fill value over water, representing no domain test/water/invalid input.

Description of Metadata:
Example of AVHRR-Land_v005-preliminary_AVH15C1_METOP_B_20191028_c20210428160140.nc

_NCProperties = version=1|netcdflibversion=4.4.1.1|hdf5libversion=1.8.17
title = Leaf Area and Fraction of Absorbed Photosynthetically Active Radiation parameters derived from METOP-B GAC data for day 2019/301

keywords = EARTH SCIENCE > BIOSPHERE > VEGETATION > VEGETATION INDEX, EARTH SCIENCE > BIOSPHERE > VEGETATION > PHOTOSYNTHETICALLY ACTIVE RADIATION
Conventions = CF-1.6, ACDD-1.3
platform = METOP-B > Meteorological Operational Satellite - B
sensor = AVHRR > Advanced Very High Resolution Radiometer
standard_name_vocabulary = CF Standard Name Table (v27)
keywords_vocabulary = NASA Global Change Master Directory (GCMD) Science Keywords
platform_vocabulary = Global Change Master Directory (GCMD) Platform Keywords
instrument_vocabulary = Global Change Master Directory (GCMD) Instrument Keywords
institution = NASA/GSFC/SED/ESD/HBSL/TIS/MODIS-LAND > MODIS Land Science Team, Terrestrial Information Systems, Hydrospheric and Biospheric Science Laboratory, Earth Sciences Division, Science and Exploration Directorate, Goddard Space Flight Center, NASA
metadata_link = https://doi.org/10.7289/V5TT4P69
program = NOAA Climate Data Record Program for satellites
cdr_variable = LAI, FAPAR
cdm_data_type = Grid
date_created = 2021-04-28T16:01:40Z
time_coverage_start = 2019-10-28T00:00:00Z
time_coverage_end = 2019-10-28T23:59:59Z
geospatial_lat_min = -90.000000
geospatial_lat_max = 90.000000
geospatial_lon_min = -180.000000
geospatial_lon_max = 180.000000
spatial_resolution = 0.050000 degrees per pixel
source = M1_AVH01C1.A2019301.005.2021118115711.hdf, LANDCOVER_IGBP_1981_1994.hdf, PGE11_band01_BRDF_slope_intercept_params.hdf, PGE11_band02_BRDF_slope_intercept_params.hdf
license = See the Use Agreement for this CDR available from the NOAA CDR webpage
Process = LTDR_GAPS
PostProcessingVersion = 2.10
product_version = v5r0-preliminary
VersionID = 3.5.54
Satellite = METOP-B
Instrument = AVHRR
InputDataType = GAC
summary = AVHRR GAC data from METOP-B for 2019, days 301 to 301, processed by the Long-Term Land Data Record (LTDR) project (v3.5.54) into Leaf Area, Fraction of Absorbed Photosynthetically Active Radiation and quality-control flags. This preliminary data corresponds to near real time processing. The preliminary data will be replaced by the final data at the beginning of the next calendar year.
ProductionTime = 2021-04-28T16:01:40.000Z
ShortName = M1_AVH15C1_NC
identifier_product_doi = 10.5067/AVHRR/M1_AVH15C1_NC.005
identifier_product_doi_authority = https://www.doi.org
LongName = METOP-B AVHRR Atmospherically Corrected Leaf Area Index and Fraction of Absorbed Photosynthetically Active Radiation Daily L3 Global 0.05 Deg CMG NetCDF
LocalGranuleID = AVHRR-Land_v005-preliminary_AVH15C1_METOP-B_20191028_c20210428160140.nc
id = AVHRR-Land_v005-preliminary_AVH15C1_METOP-B_20191028_c20210428160140.nc
naming_authority = gov.noaa.ncei
RANGEBEGINNINGDATE = 2019-301
RANGEBEGINNINGTIME = 00:00:00.0000
RANGEENDINGDATE = 2019-301
RANGEENDINGTIME = 23:59:59.9999

3.6. Data product quality flags

Table 9. AVH15C1 QA bits. Note that bit 0 is the Least Significant Bit (LSB).

Bit No.	Parameter Name	Bit value	
0 – 1	Quality control	00	OK
		01	Input flag as cloudy
		10	Invalid input
		11	Output out of range
2 – 5	Associated Class	001	Needleleaf Forest
		010	Broadleaf Forest
		011	Shrublands
		100	Grasslands & Croplands & Non vegetated
		101	Evergreen broadleaf forest
		110	Water
6	BRDF corrected	0	No
		1	Yes
7 – 8	Domain definition test	00	in Domain definition
		01	not in Domain definition
		10	not tested (water/cloudy)
9 – 15	unused		

Table 10. AVH01C1 BRDF_QA bits. Note that bit 0 is the Least Significant Bit (LSB).

Bit No.	Parameter Name	Bit value	
0	Band 1 BRDF corrected	0	No
		1	Yes
1	Band 1 BRDF corrected with adjacent parameters	0	No
		1	Yes
2	Band 1 not BRDF corrected, bad parameters	0	No
		1	Yes
3	Band 1 not BRDF corrected, high solar zenith	0	No
		1	Yes
4		0	No

	Band 1 not BRDF corrected, water	1	Yes
5	Band 2 BRDF corrected	0	No
		1	Yes
6	Band 2 BRDF corrected with adjacent parameters	0	No
		1	Yes
7	Band 2 not BRDF corrected, bad parameters	0	No
		1	Yes
8	Band 2 not BRDF corrected, high solar zenith	0	No
		1	Yes
9	Band 2 not BRDF corrected, water	0	No
		1	Yes
10 – 15	unused		

Table 11. QC/QA bits for AVH01C1, -02C1, -09C2 and -13C1. Note that bit 0 is the Least Significant Bit (LSB).

Bit No.	Parameter Name	Bit value	
0	unused		
1	Pixel is cloudy	0	No
		1	Yes
2	Pixel contains cloud shadow	0	No
		1	Yes
3	Pixel is over water	0	No
		1	Yes
4	Pixel is over sunglint	0	No
		1	Yes
5	Pixel is over dense dark vegetation	0	No
		1	Yes
6	Pixel is at night (high solar zenith)	0	No
		1	Yes
7	Channels 1 – 5 are valid	0	No
		1	Yes

8	Channel 1 value is invalid	0	No
		1	Yes
9	Channel 2 value is invalid	0	No
		1	Yes
10	Channel 3 value is invalid	0	No
		1	Yes
11	Channel 4 value is invalid	0	No
		1	Yes
12	Channel 5 value is invalid	0	No
		1	Yes
13	RHO3 value is invalid	0	No
		1	Yes
14	BRDF corrected	0	No
		1	Yes
15	Polar flag (latitude over/under +/-60 degrees (land) or +/-50 degrees (ocean))	0	No
		1	Yes

3.7. Number Mapping

Table 12. AVH01C1 N_MAPPING bits. Note that bit 0 is the Least Significant Bit (LSB).

Bit No.	Description
0-3	Number of pixel mapping to here flagged as cloudy
4-7	Number of pixel mapping to here flagged as cloud shadow
8-11	Number of pixel mapping to here flagged as adjacent to cloud
12-15	Number of pixel mapping to here flagged for snow
16-19	Number of pixel mapping to here flagged for using low gain in band 1
20-23	Number of pixel mapping to here flagged for using low gain in band 2
24-31	unused

3.8. Additional Products

Two types of files – AVH09C1 and AVH13C1 – are also available in the NetCDF format. The NetCDF versions of AVH09C1 and AVH13C1 (like the AVH15C1 file) contain data similar to their HDF4 counterparts, but also contain the data structures and metadata required for the files to represent a Climate Data Record (CDR), because these NetCDF files are to be used in NOAA's Climate Data Record program (see https://www.ncdc.noaa.gov/cdr/terrestrial/avhrr-surface-reflectance, https://www.ncdc.noaa.gov/cdr/terrestrial/normalized-difference-vegetation-index, and https://www.ncdc.noaa.gov/cdr/terrestrial/leaf-area-index-and-fapar).

One addition for a CDR is that the datasets in the files need to be of three dimensions (latitude, longitude, and time), with the time dimension consisting of 1 – e. g., each pixel is considered to be sampled at 00:00 of the data-day. Also, each dimension has a corresponding one-dimensional coordinate variable dataset, consisting of values it takes (e. g., the 'latitude' dataset consisting of values running from 90.0 to -90.0). Lastly, a CDR is expected to have set of self-documenting metadata, ranging from global metadata (conventions, title, source, references, history, comment, et cetera) to flag_values, flag_masks and flag_meanings for bitmapped datasets.

3.9. Satellites from which AVHRR data was processed

GAC data used by the LTDR project has been obtained only from AVHRR on board ascending node satellites, with afternoon equator crossing times. That works out to approximately every-other NOAA satellite that was launched. The following table lists which satellites' data was used in the LTDR project, and the years and days which were processed for that satellite.

Table 13. Satellites from which AVHRR data was processed.

ESDT prefix (table 3)	Satellite	Start (year, Julian day)	End (year, Julian day)
N07	NOAA-07	1981-175	1985-033
N09	NOAA-09	1985-004	1988-312
N11	NOAA-11	1988-313	1994-365
N14	NOAA-14	1995-001	2000-305
N16	NOAA-16	2000-306	2007-365
N18	NOAA-18	2005-182	2009-365
N19	NOAA-19	2009-151	Present dayt[a]
M1	MetOP-B	2013-016	Present day

[a] – NOAA-19 processing continues to the present day, but orbital decay of NOAA-19 has made data from 2017 onward of limited usefulness.

4. Caveats and Known Problems

The performance of the atmospheric correction algorithm degrades as the view and solar zenith angles get larger and as aerosol optical thickness increases; also, the algorithm is less accurate for bands at shorter wavelengths. The level of accuracy of the atmospheric correction is typically within ±(0.005 + 0.05*reflectance) under favorable conditions (no high aerosol loading). The look-up tables used in the atmospheric correction algorithm assume upper limits of 5.0 for aerosol optical thickness and 75° for solar zenith angles. A long-term evaluation of AVHRR surface reflectance data showed that, in general, the LTDR V5 performed within ±(0.0071 + 0.071*reflectance) of the Landsat-5 Thematic Mapper Collection 1 surface reflectance product (Santamaria-Artigas et al., 2021).

For NOAA-19, orbital decay has resulted in progressively later equator crossing times, which has elevated solar zenith angles correspondingly. Data past year 2016 is not recommended for quantitative analysis. Data toward the end-time of processing for other satellites (in Table 13) should also be regarded as questionable.

In the cloud mask, snow is tagged as cloud.

5. Data ordering

5.1. Where to get data from

All file types listed in Table 2 are available at the following websites:

NOAA National Centers for Environmental Information

AVH09C1 (NetCDF only)
At https://www.ncdc.noaa.gov/cdr/terrestrial/avhrr-surface-reflectance

AVH13C1 (NetCDF only)
At https://www.ncdc.noaa.gov/cdr/terrestrial/normalized-difference-vegetation-index

AVH15C1 (NetCDF only)
At https://www.ncdc.noaa.gov/cdr/terrestrial/leaf-area-index-and-fapar

LAADS: Level 1 and Atmosphere Archive & Distribution System
At https://ladsweb.modaps.eosdis.nasa.gov/ users can download the following products:

XX_AVH01C1 (HDF4 only)
XX_AVH02C1 (HDF4 only)
XX_AVH09C1 (HDF4 and NetCDF)
XX_AVH13C1 (HDF4 and NetCDF)
XX_AVH15C1 (NetCDF only)

where XX is N07, N09, N11, et cetera.

5.2. Data product granule ID

All archived data is accessed by its LOCALGRANULEID.
For HDF4 data, the LOCALGRANULEID is constructed like this:
Example 1: M1_AVH13C1.A2019301.005.2021118115711.hdf

M1_AVH13C1: product ESDT name (see **Table 2**)
A2019301: Acquisition year (2019) and Julian day (301)
005: Re-Processing version number 5 (V5)
2021118115711: Production year (2021), Julian day (118), and time (11:57:11)
hdf: HDF4 format

For NetCDF data (CDRs), the LOCALGRANULEID is constructed like this:
Example 2: AVHRR-Land_v005-preliminary_AVH15C1_METOP-B_20191028_c20210428160140.nc.
AVHRR-Land: product name
v005-preliminary: Re-Processing version number 5 (V5)
AVH15C1: product ESDT name (see **Table 2**)
METOP-B: satellite ID
20191028: Acquisition year (2019), month (10) and day (28)
c20210428160140: Production (creation) year (2021), month (04), day (28), and time (16:01:40)
nc: NetCDF format

5.3. Data viewing tools.

The following are some examples of software that can be used to visualize and explore LTDR data.

a) Panoply (Linux, MacOS, and Windows)
Panoply is a free data visualization software developed by NASA that allows to plot spatial and temporal data from netCDF, HDF, GRIB, and other datasets.
Link: https://www.giss.nasa.gov/tools/panoply/

b) HDFLook (Linux, MacOS, and Cygwin)
A multifunctional data processing and visualization tool for land, ocean, and atmosphere HDF data.
Link: https://hdfeos.org/software/HDFLook.php

c) ENVI (Linux, MacOS, and Windows)
Software for the visualization, analysis, and presentation of numerous types of digital imagery.
Link: https://www.l3harrisgeospatial.com/Software-Technology/ENVI /

d) HDF Explorer (Windows)
A software environment where data are first viewed in a tree-like interface, and then optionally loaded and visualized in a variety of ways.
Link: https://www.hdfeos.org/software/hdfexplorer.php

6. References

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Franch, Belen, et al. "A 30+ year AVHRR land surface reflectance climate data record and its application to wheat yield monitoring." *Remote Sensing* 9.3 (2017): 296.

Ouaidrari, H, El Saleous N, Vermote EF, Townshend JR and Goward SN. AVHRR Land Pathfinder II (ALP II) data set: evaluation and inter-comparison with other data sets. *International Journal of Remote Sensing*, 2003; 24, 135–142. https://doi.org/10.1080/01431160305006

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